Mitigation of Point Absorbers in the Advanced Virgo plus core optics: the actuator design

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GWADW – Gravitational-Wave Advanced Detector Workshop, May 21st-27th, 2023
Hotel Hermitage, La Biodola, Isola d'Elba

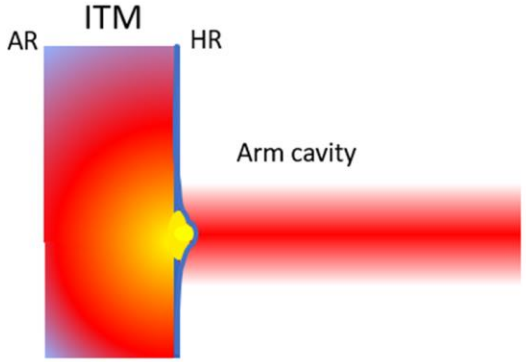
Outline

- Point Absorbers' problem
- Point Absorbers on the AdV+ test masses
- Correction profile
- Actuator's design
- Optical and mechanical layout
- Actuator's assembly
- Validation tests

Point Absorbers' problem

Characteristics:

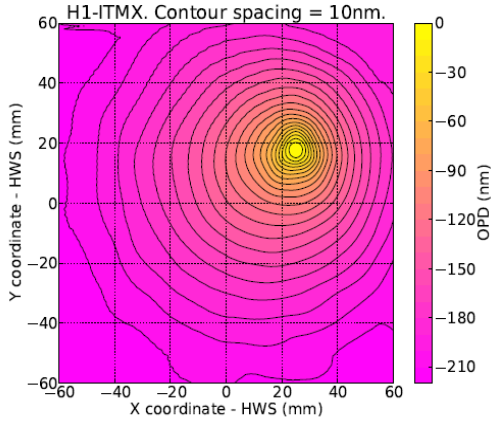
- Localized small
- Randomly present on the HR mirror surfaces
- Highly absorbing
- Embedded in the coating
- Can not be cleaned
- Composition of high concentration of Aluminium

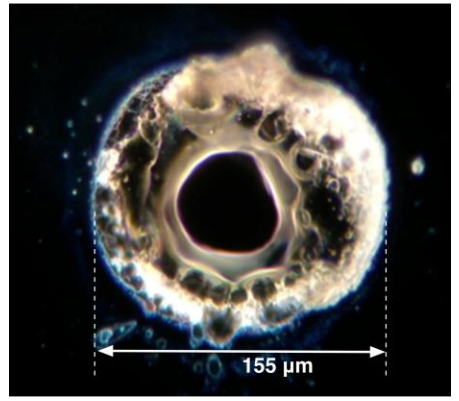


Effects of their presence:

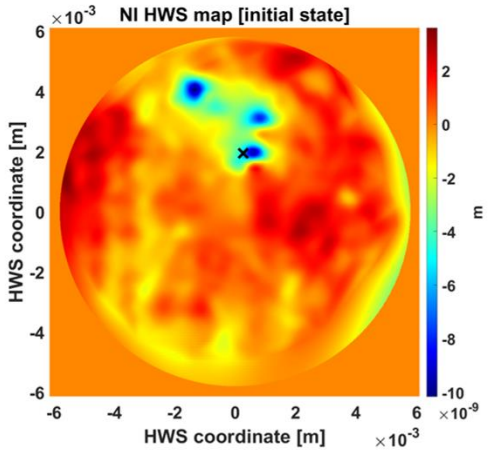
- Scattering into HOM
- Increase of round-trip losses
- Limits interferometer sensitivity

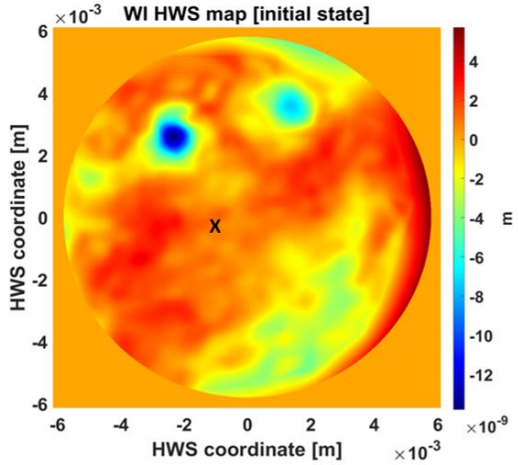
Discovered during the O3 observing run on both LIGO and Virgo test masses → Increase of the ITF laser power



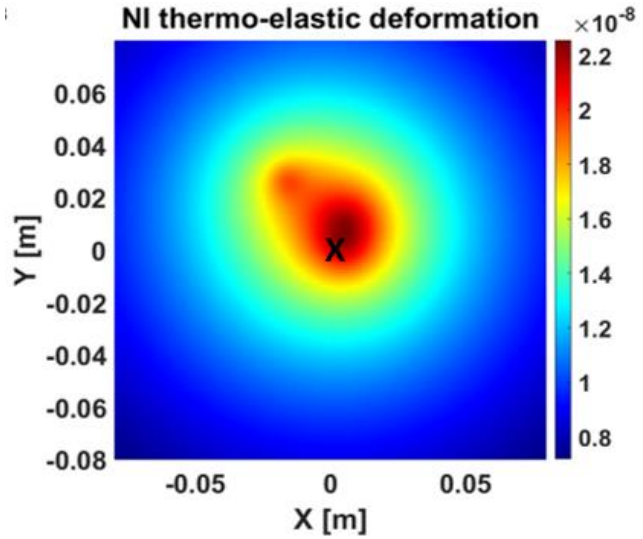


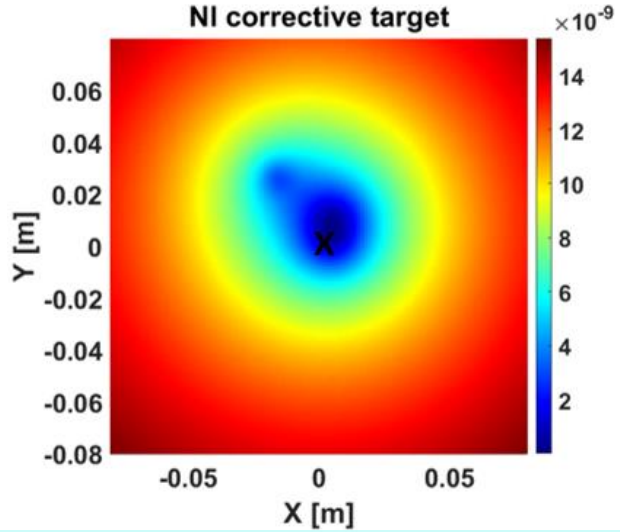
[arXiv:2101.05828]





Point Absorbers in Virgo



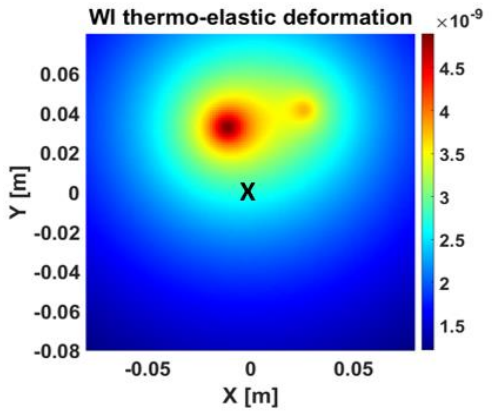


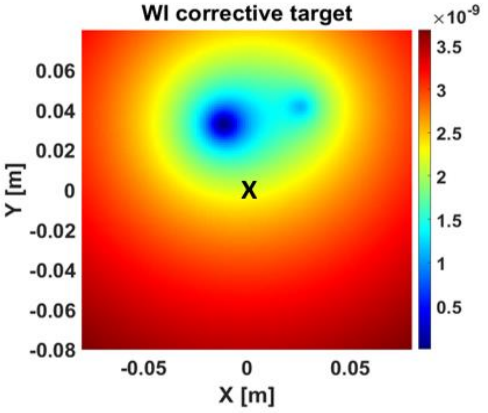
HWS measurements (OPL variation map) allowed to identify the presence and the distribution of the points on the mirrors.

Thermo-elastic deformations and relative corrections evaluated with FEA simulations.

The WI case: Under investigation

In November 2022, after a deep cleaning procedures, the WI points disappeared





Actuation profile

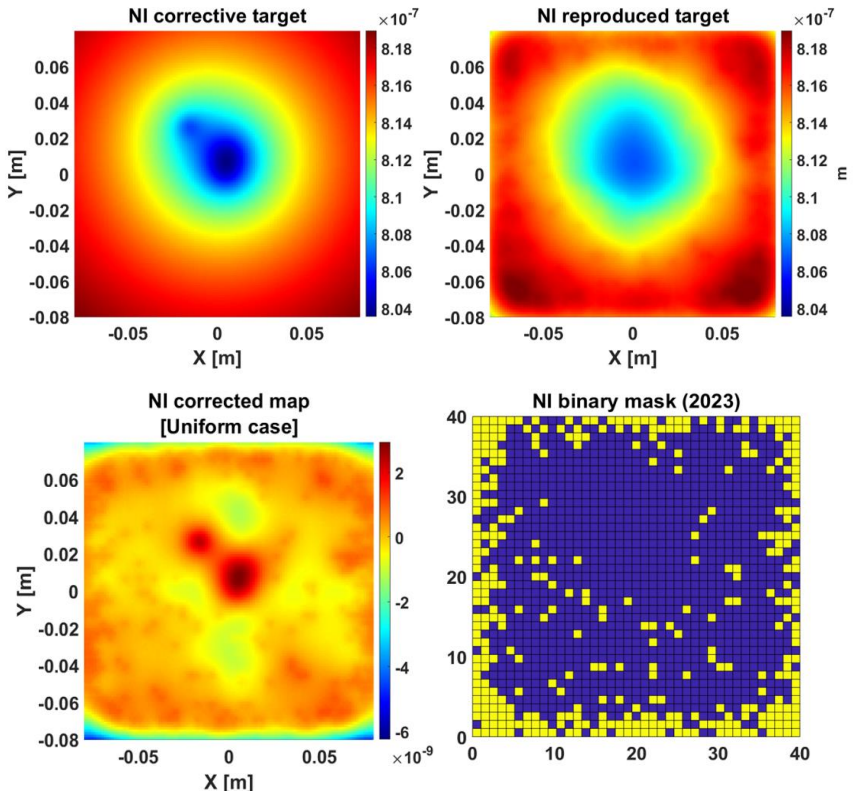
The actuation profile has been evaluated starting from influence functions and by applying the **influence matrix formalism**

2 cases:

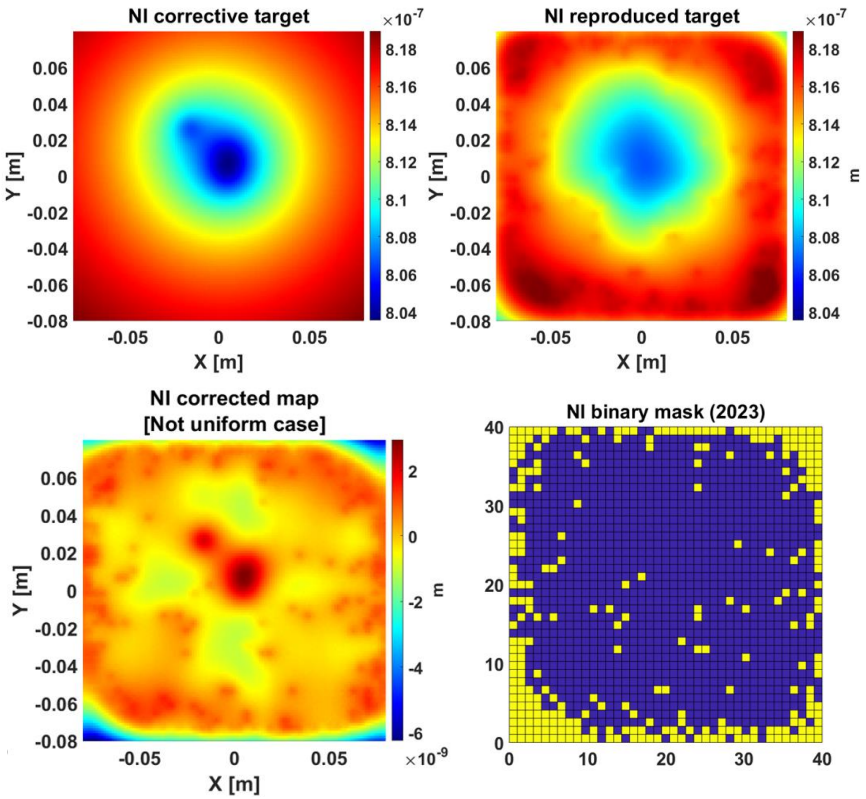
- Uniform radiation
- No-uniform radiation

Final idea: Binary matrix with 40x40 actuators

Uniform radiation:



No-uniform radiation:

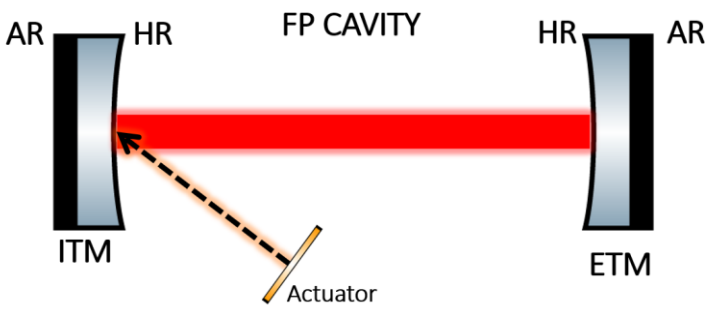


Corrective pattern has been evaluated with Matlab codes and checked with FEA (2D and 3D) and optical simulations

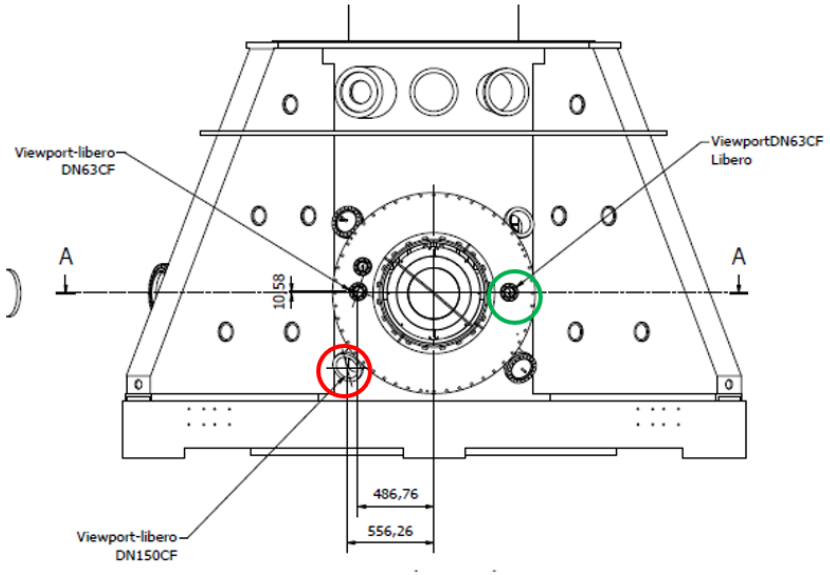
Correction of the order of 30%

Actuator's design

General idea



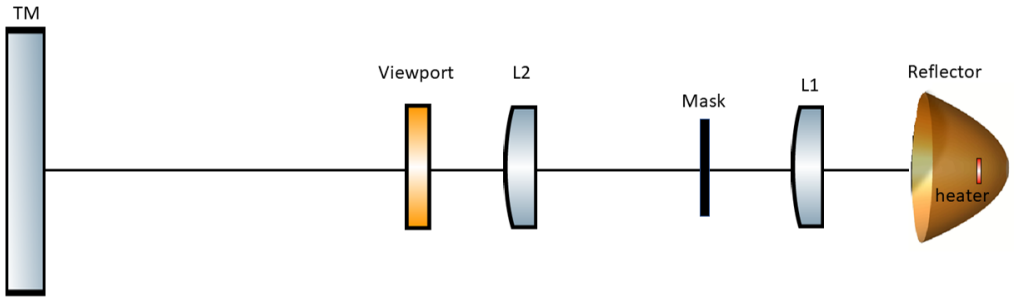
- Designed to be installed on all the towers
- Out of the vacuum system (easily upgradable)
- Facing the HR surface



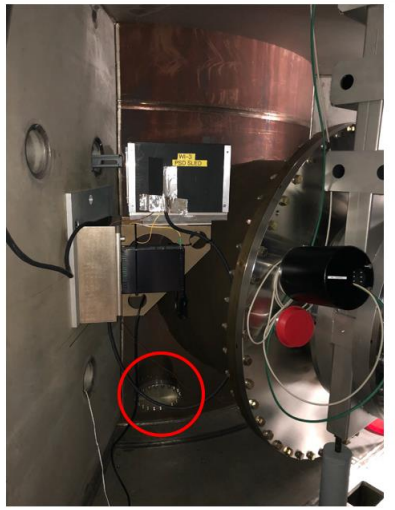
Viewport	D [mm]	AOI_1 [°]	AOI_2 [°]	d [mm]
DN150CF	150	30	28	1048
DN63CF	63	18.2	0	1558

Actuation

Diagnostic

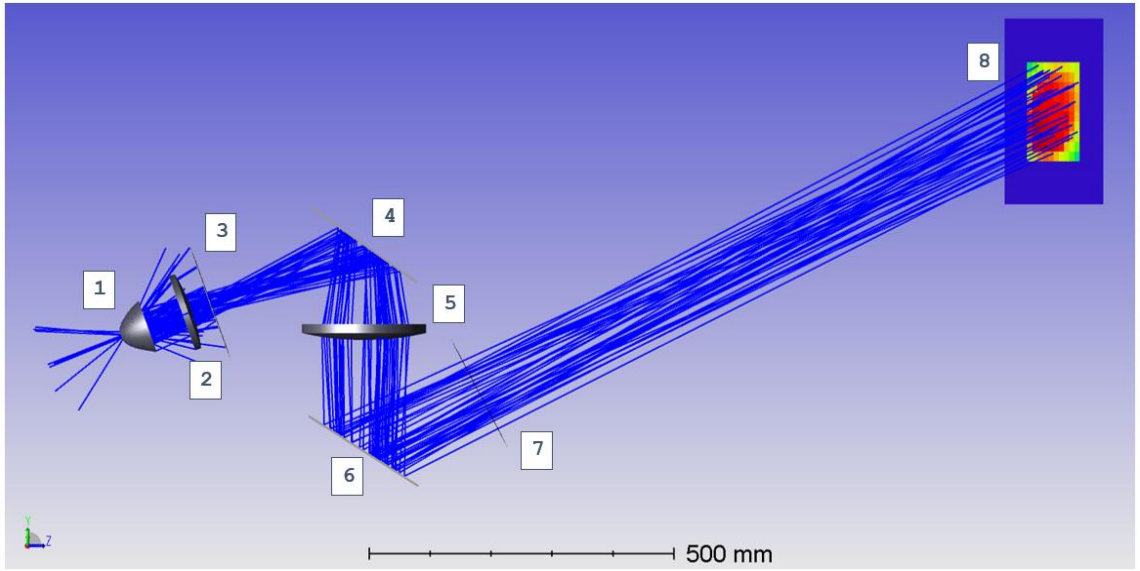


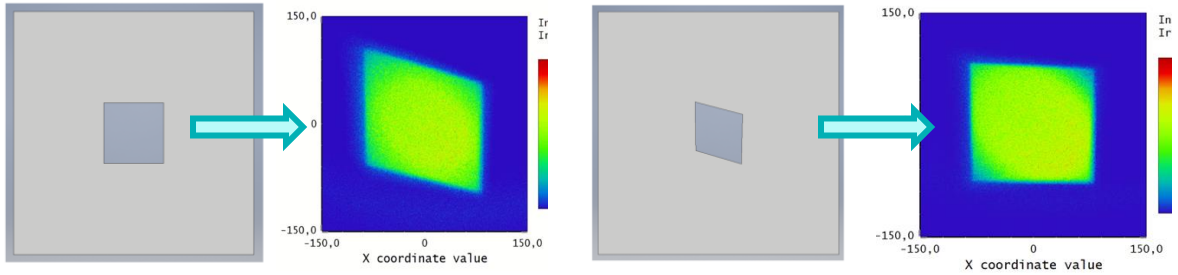
The choice of the viewport determine the entire optical layout



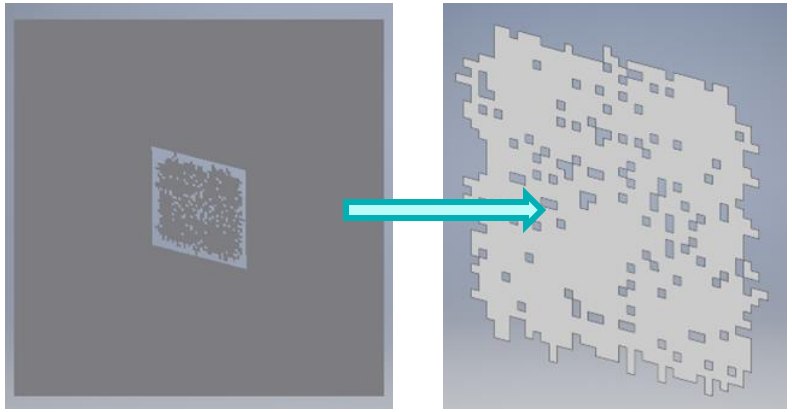
Optical layout

Final version





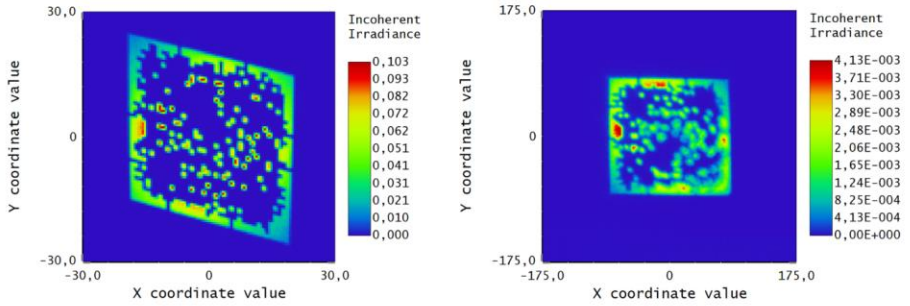
Distances and optical element sizes have been evaluated to fulfil the efficiency requirements and the available space



Components:

1: Parabolic reflector and ceramic heater
2: Focusing Germanium Lens (L1) (5")
3: Binary mask
4-6: Steering mirrors
5: Magnification factor Germanium Lens (L2) (8")
7: ZnSe viewport
8: Test Mass

AOIs influence the shape and the distribution of the radiation on the TM



Object plane

Image plane

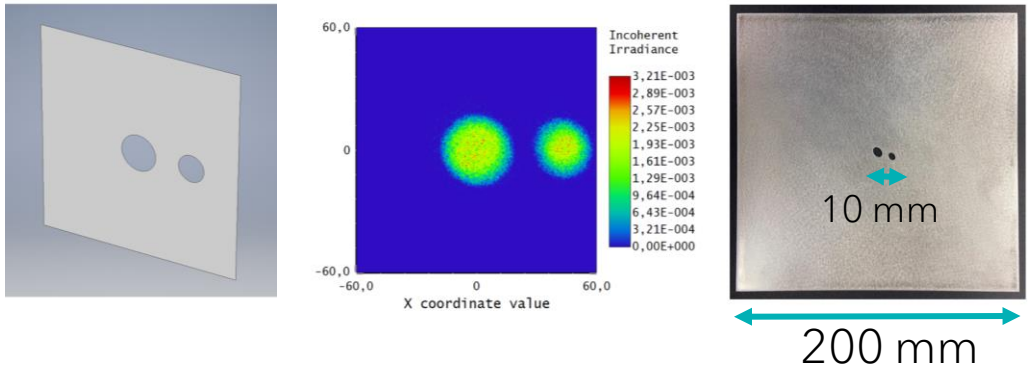
Alignment masks

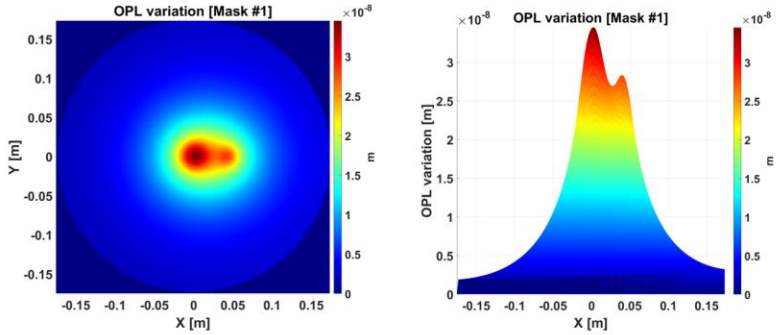
Goals:

1: Align the heating pattern on the mirror
2: Identify the image direction

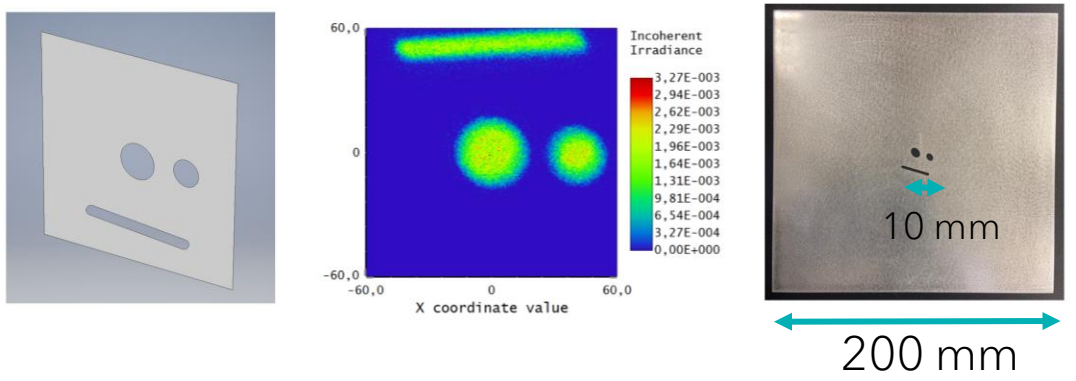
The alignment masks have been designed with ray tracing and FEA simulations

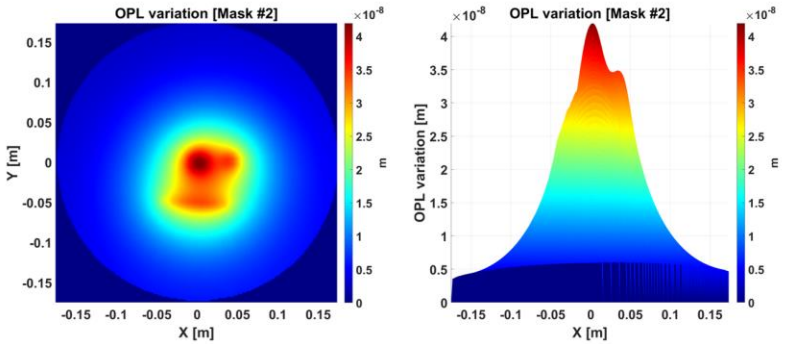
Mask #1





Mask #2

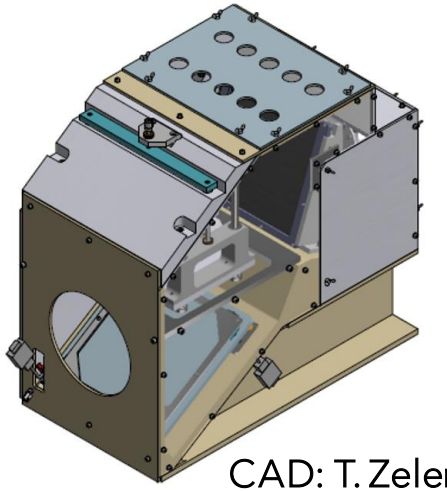


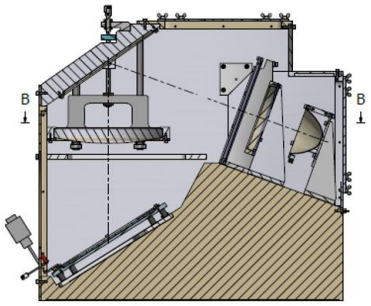


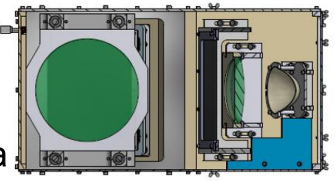
Mechanical layout

Guidelines:
- Total efficiency
- Compactness and available space
- Components dimensions, costs and manufacturing times
- Adaptability

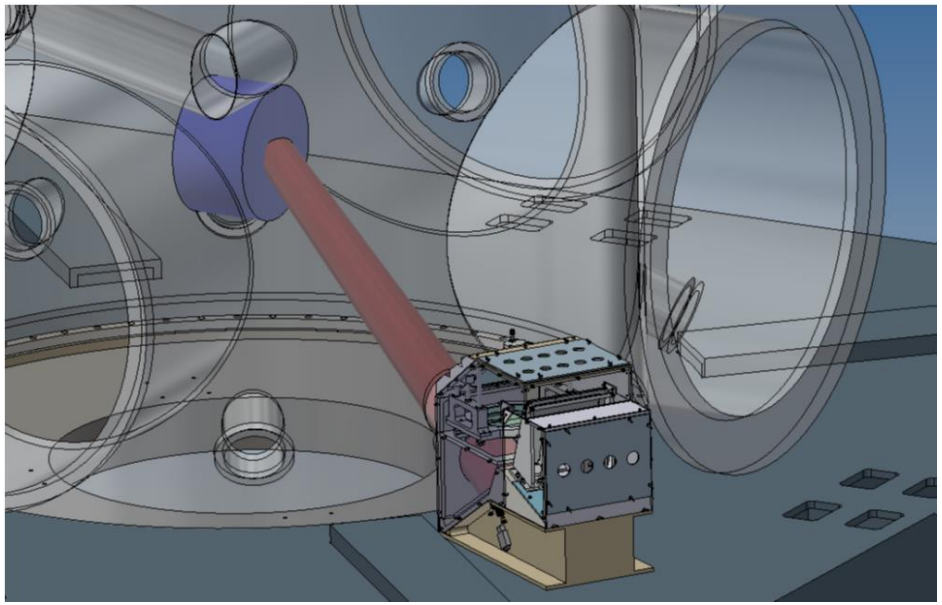
- Remote control of M2 (closed loop picomotors)
- Manual control of L2, L1 and mask
- Remote control of the heater power and temperature







CAD: T. Zelenova

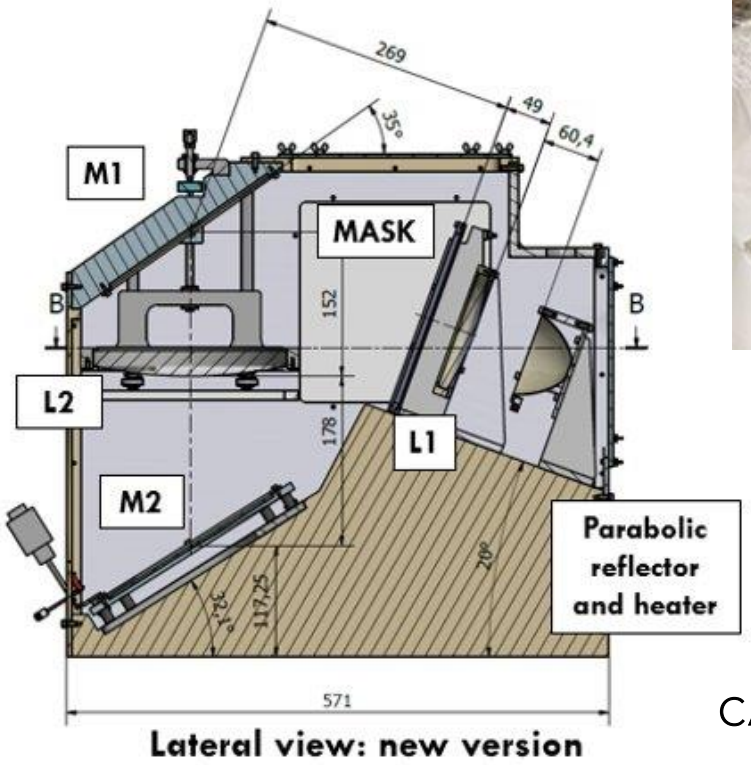


CAD: T. Zelenova

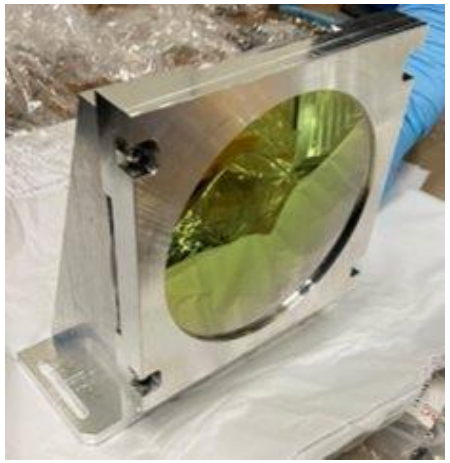
Actuator assembly

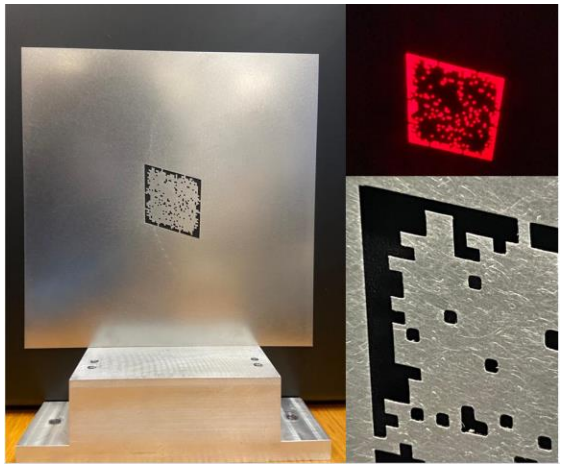
Pre-assembly test performed in December 2022
First assembly in April 2023

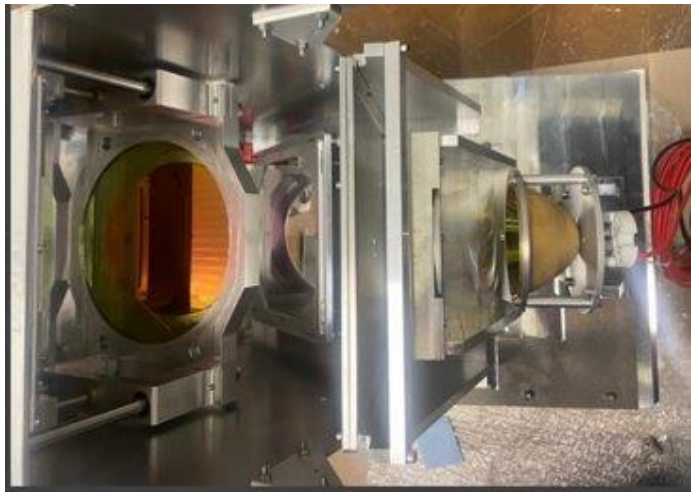
Actuator characterization



CAD: T. Zelenova







Validation tests

Heater characterization

Steps:

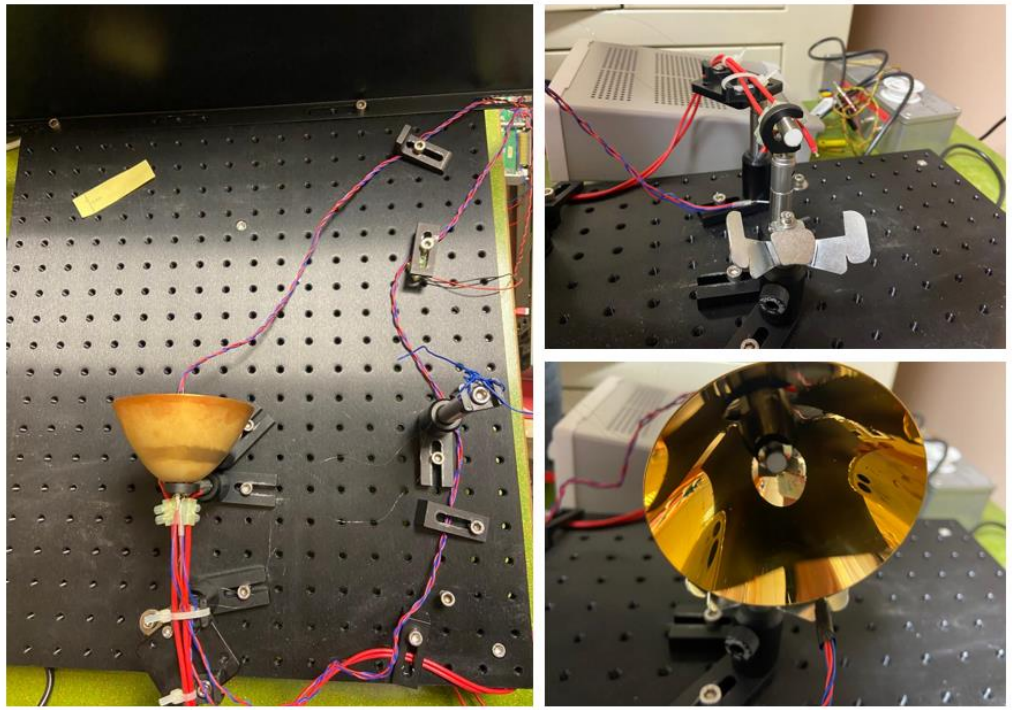
1: Inspection of the optical components
2: Characterization of the heater
3: Validation of the actuator

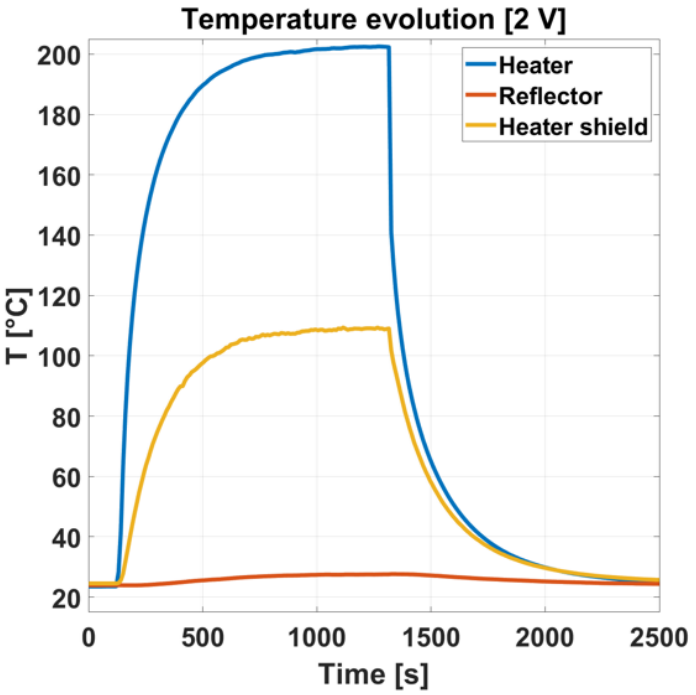
The heater is supplied in voltage and controlled in temperature by a thermo-couple

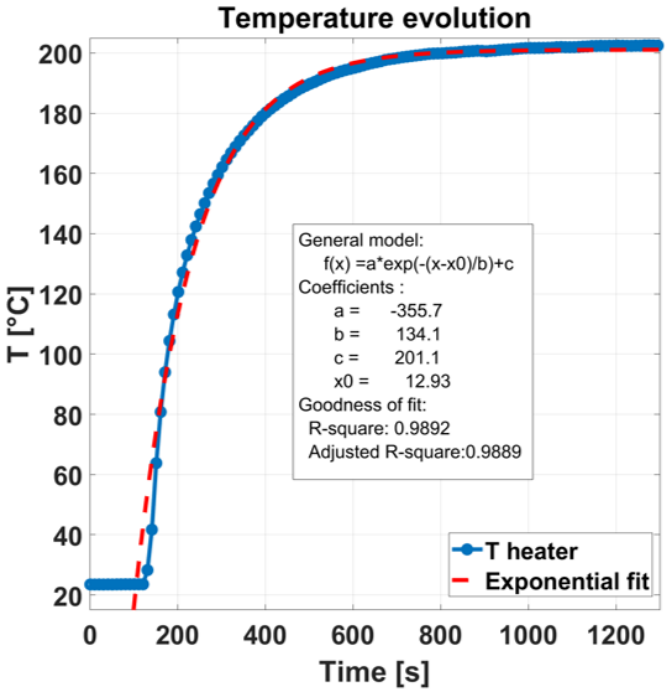
Thermalization time:

$$f(x) = a \cdot e^{-\frac{x - x_0}{b}} + c$$

Around 3 min







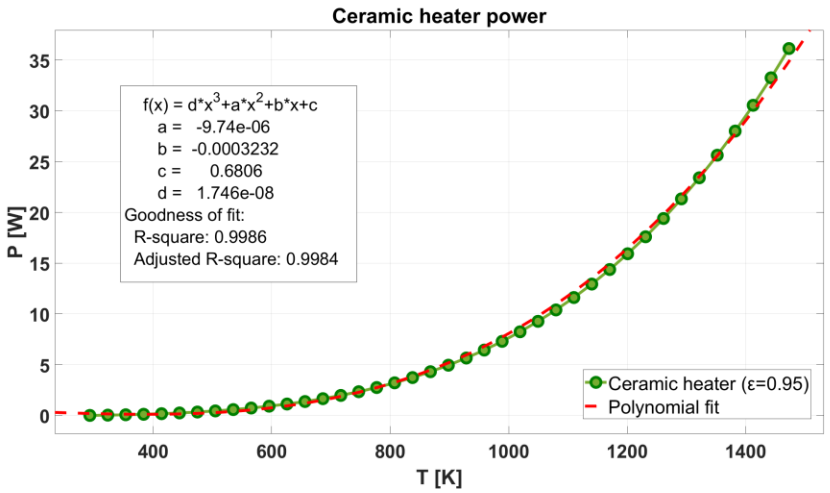
Validation tests

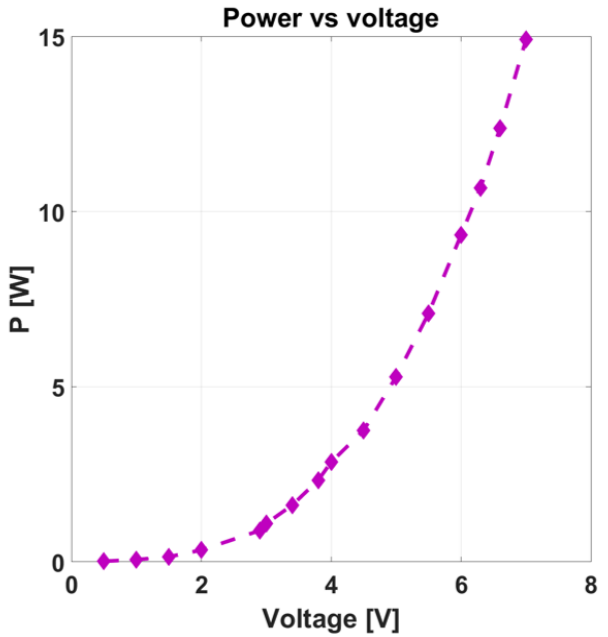
Heater characterization

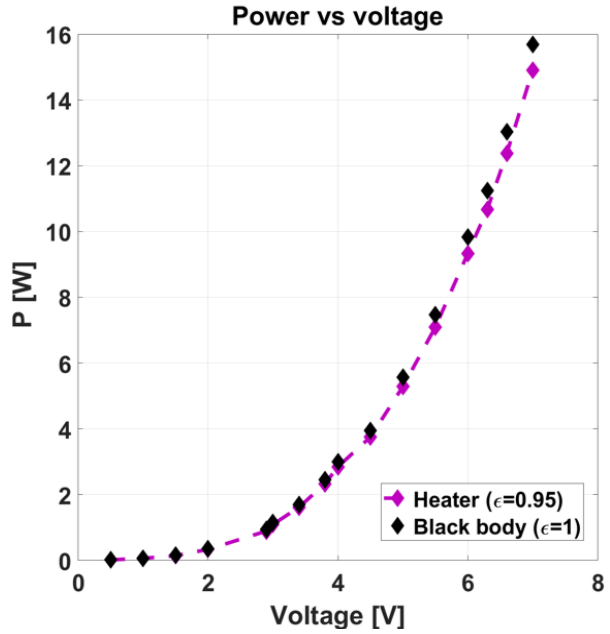
Heater maximum T: 1200 °C
Maximum tested T: almost 900 °C
Maximum tested voltage: 7 V

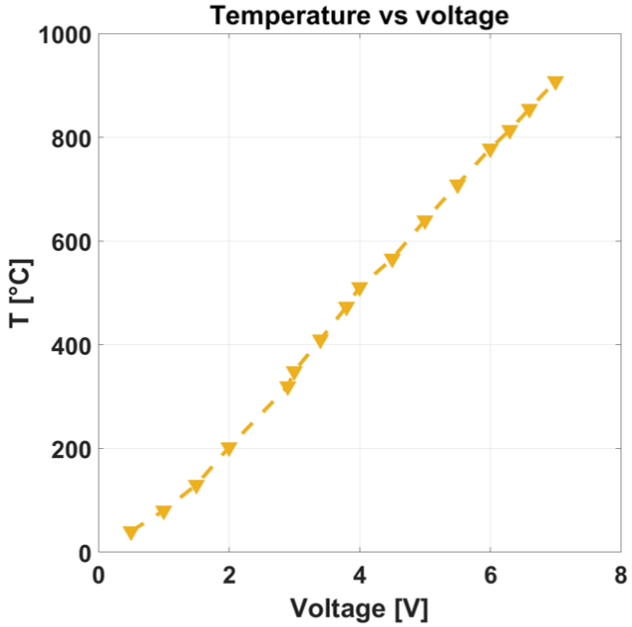
With the approximation of the Black Body radiation, the heater power can be estimated as:

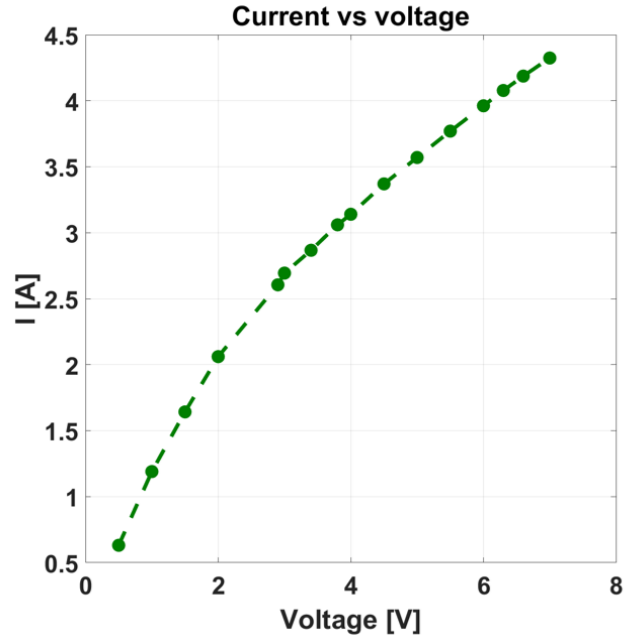
$$P_H = \epsilon \sigma A (T^4 - T_0^4)$$





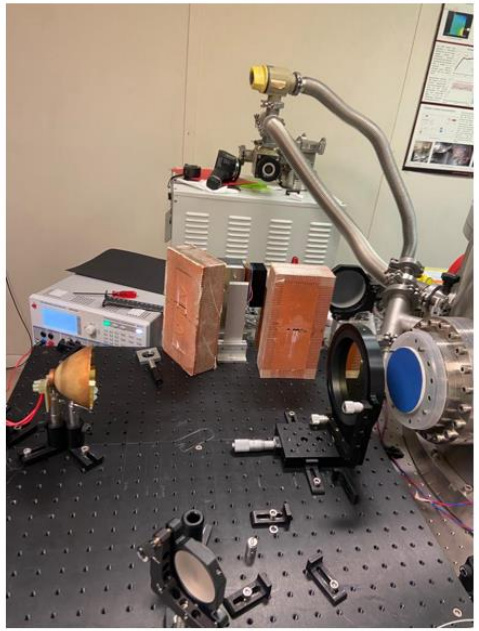


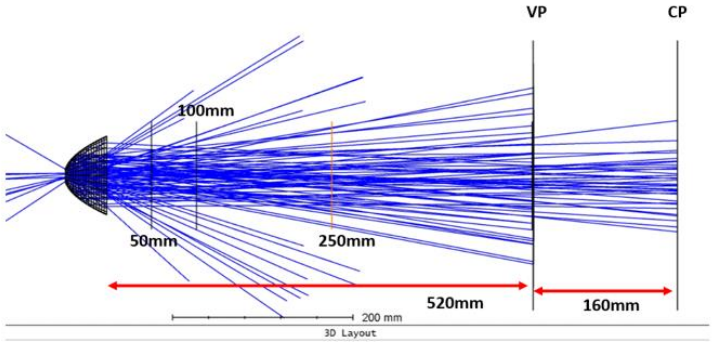




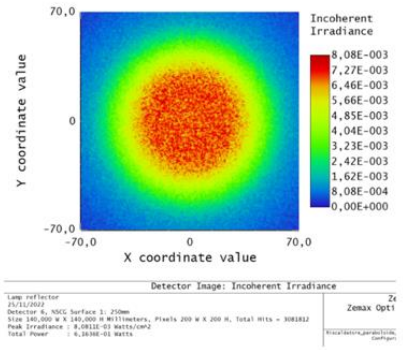
Validation tests

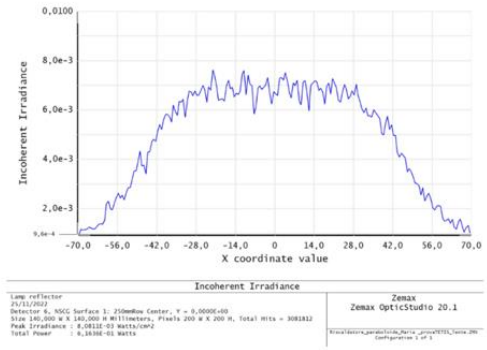
Actuator characterization

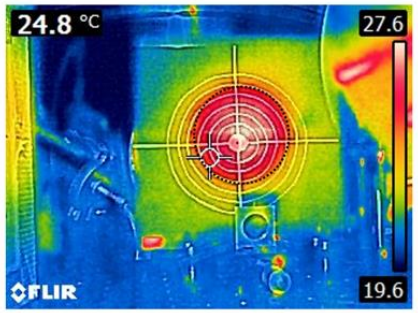


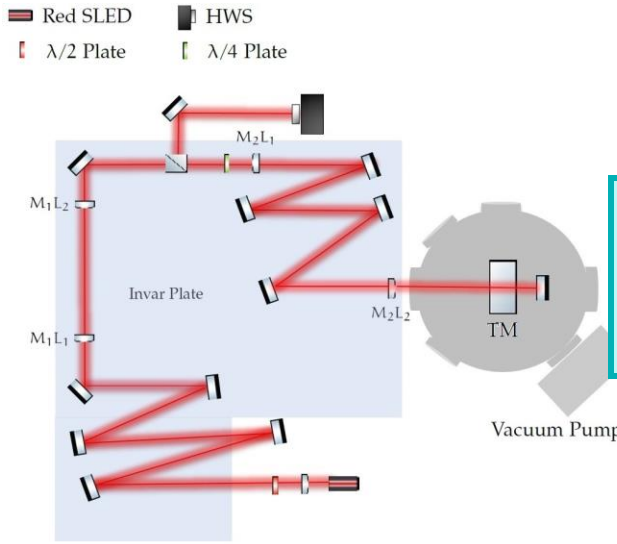


1: Check of the radiation size at different distances (ray tracing and thermal camera)
2: Check of the radiation dimension on the CP (ray tracing and thermal camera)
3: Comparison of the OPL variation: theoretical (MatTherm) and experimental (measured with a HWS in Tor Vergata Test Facility)







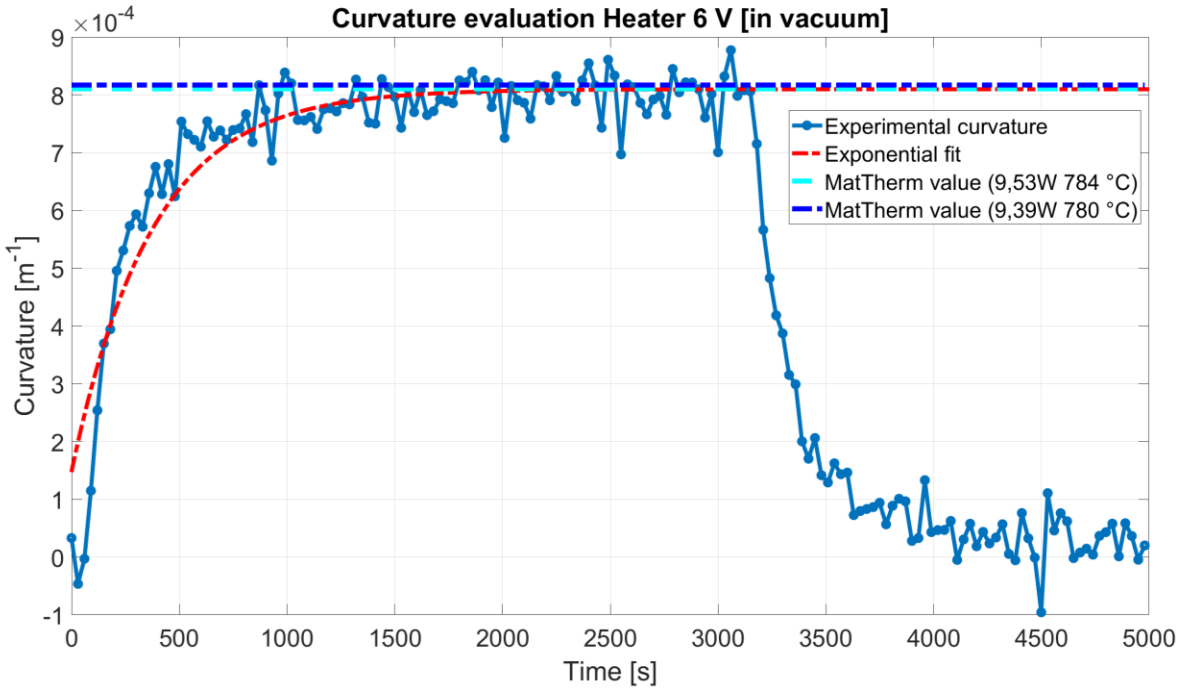


Test bench

Validation tests

Actuator characterization

$Curv_S$ is the simulated curvature
$Curv_E$ is the experimental curvature



Simulations have been made at the steady-state

V [V]	T [°C]	P_H [W]	P_{CP} [W]	$Curv_S$ [10^{-4}m]	$Curv_E$ [10^{-4}m]	%
5.5	723	7.5	3.5	6.497	6.84	5
6	784	9.53	4.42	8.103	8.049	2
7	890	14	6.51	10.58	12.042	12

Conclusions and future plans

- Point Absorbers on the AdV+ mirrors have been analysed and characterized
- The desired corrective heating profile has been identified
- The optical layout and the mechanical housing design of the actuator has been fully developed to be compliant with the requirements
- The components procurement and the first actuator's assembly have been completed and the connections checked
- The pre-installation tests are ongoing

The installation is planned for the first half of June 2023

BACKUP SLIDES

GWADW – Gravitational-Wave Advanced Detector Workshop, May 21st-27th, 2023
Hotel Hermitage, La Biodola, Isola d'Elba

Actuator's pre-installation tests

Pre-installation

- Check of the electrical connections
- Check of the remote-control connection and thermo-couple acquisition
- Temperature control of the entire setup
- Heater characterization/calibration (power vs. temperature) after the installation of the cover
- Check of the heating profile projection with thermal camera both for the alignment and test masks (shape and magnification factor)

After installation and commissioning:

- Preparation for the installation procedures
- Alignment procedures and validation of the final mask

Actuator's installation strategy

- **Step 1:** installation of a sliding floor between the tower and the scaffolding
- **Step 2:** transport of the PA close to the slide deck by means of a trolley on swivel wheels
- **Step 3:** positioning on the tower base using the ball bearing units installed on the PA base